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Effect of Track Curvature in The Operation of Electric Cars

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EFFECT OF TRACK CURVATURE

IN THE

OPERATION OF ELECTRIC CARS

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOHN OSCAR KAMMERMAN and DWAYNE GLOVER YOUNG

ENTITLED EFFECT OF TRACK CURVATURE IN THE OPERATION OF ELECTRIC CARS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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It has always been a well known fact that a greater speed can be obtained on a straight road than on a curved road. Thus time may be saved in going from one place to another by direct route and the saving of time means a saving of power and money in the operation of electric cars.

In former years in the construction of a road bed the curvature of the tracks were not considered and often long curves were built aruond obstacles to cheapen the cost of construction. The money lost on the operation of cars on these curves was not considered. But it is a fact that the cost of the extra power used due to these curves would soon pay for the removal of the obstacle. Especially in passenger service where competition demands that the greatest speed possible should be obtained,curves are a great hinderance as the speed of a train must be reduced to a certain extent on a great many curves,more especially on interurban track.

The data for this thesis was obtained by the use of the University Electric Test Car,on the Illinois Traction System's line between Urbana and Danville. The car was built by the St. Lous car Co. and is an ordinary type double truck,interurban car. It is driven by four forty horsepower,Westinghouse motors. The control is the Westinghouse unit control system which is operated by storage batteries with I5 volts pressure. The car is supplied with a system of brakes operated on the straight air plan and supplemented by a hand brake. The air brake equipment is built by the National Brake and Electric Co. of Milwaukee,Wisconsin.

The car contains a set of recording instruments,all of which record the same instant on a moving roll of paper which is drawn under the pens by a roller operated by a small motor which draws its current from the trolley wire. In all, this paper contains the record of the application of brakes,curve,speed,voltage,current,and the time is automatically marked every five seconds and the distance is marked every eight revolutions of the wheel in the same way. these instruments were all calibrated by use of direct reading instruments,check readings for the speed motor were taken from an autometer which reads directly in miles per hour. Every fifth pole out of Danville is numbered and any section of the chart can be located by stamping the pole number at intervals of about twenty poles. Plates I,II,III,are the calibration curves for the ammeter,voltmeter and speed meter.

In securing this data a series of runs were made between Urbana and Danville under the ordinary running conditions of the regular schedule cars;-the test car ran either as first or second section to a regular car. The chart was kept in motion the entire distance and the different conditions of the car was recorded constantly. Note was made in the log book of the weather and condition of the track. All the data for curves was taken on a dry track and mild days. For thepower consumed on curves,several special runs were made. On these tests the car was stopped on the beginning of the curve and the limit switch was short circuited,so that by throwing the controller handle into the series position,the switch group

notched up to full series connection without any delay and regardless of the current drawn by the motors. The power was applied for fifteen seconds and then shut off. Then from the chart the killowatts used over a certain length of track at a certain speed was obtained. From a profile of the road, the degree of curvature of each curve on the line was taken. The profile was supplied by Railway Engineering Department.

After half of the test runs had been made the center bearings of the car were changed. The latter half of the runs were made on ball bearing center plates. The object was to show the efficiency of the ball bearing plates. Several views of the ball bearing plates are shown on plate IV.

From the general runs the time lost by different degree curves was calculated. The speed was taken before the curve and the time noted until the same speed was again obtained beyond the curve. This gave the time consumed in passing the curve. The time required to traverse the same distance on straight track at the rate of speed before the curve, was then calculated. The difference between these two numbers of seconds was the time lost due to the curve. By taking account of all the curves on the line a good range of curves was obtained. This data is in tables, I and II. The greatest curve was a forty five degree curve. From this data a curve was plotted as shown on plates V and VI, from the time lost due to any degree curve can be taken at the speeds noted on the plates.

PLATE IV

TABLE I.

Data for Time Lost on Curves.

Speed before Curve	Degree of Curve	Speed after Curve	Distance Traveled ft.	Sec. Actual Time	Sec. Calculated Time	Sec. Time Lost
30	2°24'	30	1035	27.5	25	2.5
30	3°4'	30	828	20	18.9	1.1
30	4°40'	30	1035	25.8	23.8	2.0
30	6°30'	30	1291	31.7	28.5	3.2
30	8°30'	30	1205	29.3	25.2	4.1
30	11°30'	30	1538	39	33	6.0
30	24°	30	1000	38	22.8	15.2
30	32°	30	1315	57.5	30	27.5

PLATE V

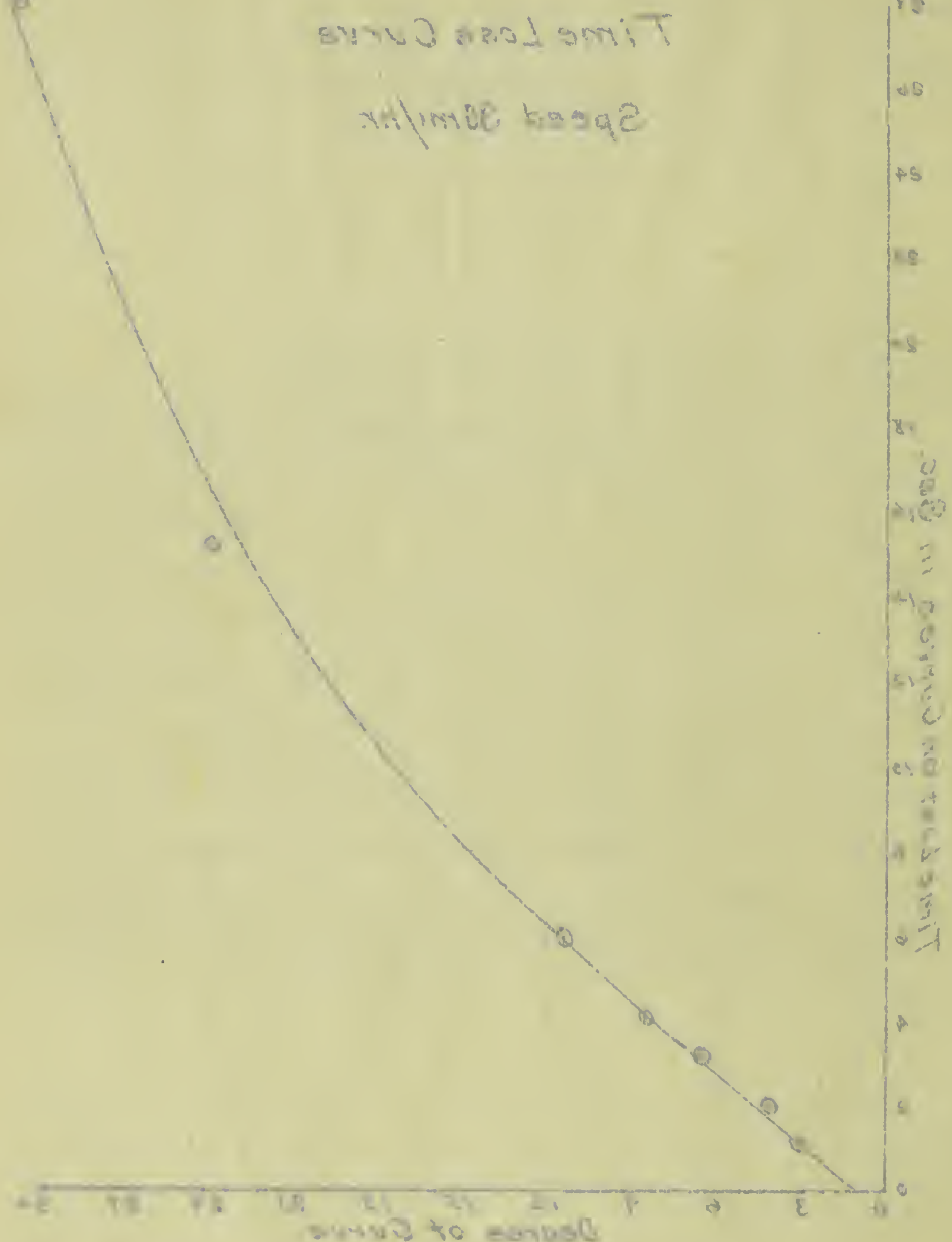
Time Loss Curve
Speed 30mi/hr
Degrees of Curve
Time Lost on Curve in Sec.

TABLE II.

Data for Time Lost on Curves.

Speed before Curve mi/hr.	Degree of Curve	Speed after Curve mi/hr.	Distance Traveled ft.	Actual Time Sec.	Calculated Time Sec.	Time Lost Sec.
40	2°24'	40	1100	20	18.7	1.3
40	3°4'	40	925	17.5	15.7	1.8
40	4°40'	40	1220	23.1	20.8	2.3
40	6°30'	40	1400	27.6	23.8	3.8
40	8°30'	40	1436	29.3	24.4	4.9
40	11°30'	40	1610	34.9	27.3	7.6
40	24°	40	1200	38.1	20.4	17.7

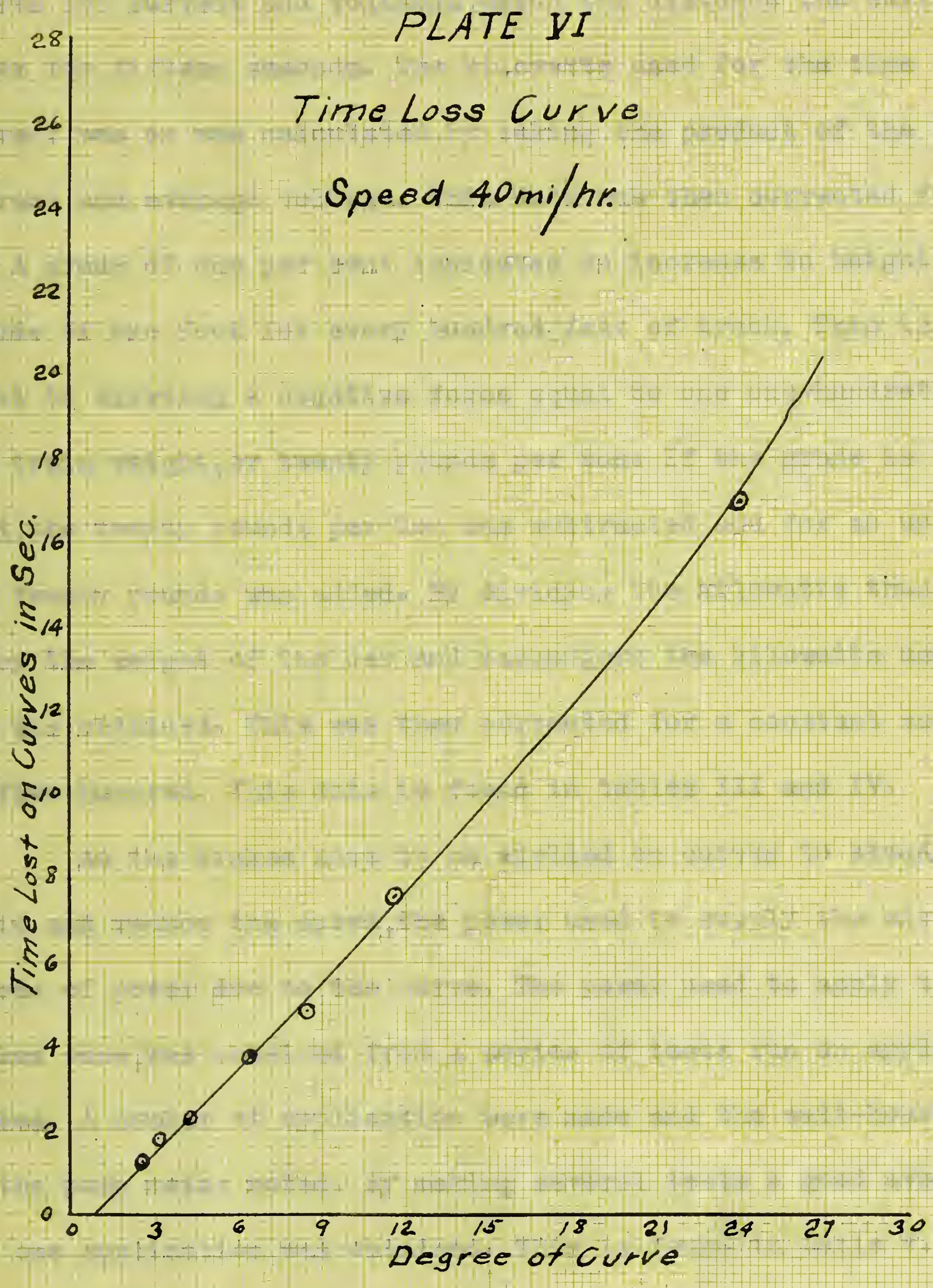
PLATE VI
Time Loss Curve
Speed 40mi/hr.
Time Lost on Curves in Sec.
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
3
6
9
12
15
18
21
24
27
30
Degree of Curve

The special tests were made to obtain data from which the power consumed was calculated. This was done by planimetering the charts for current and voltange,using the distance the current was on,or for fifteen seconds. The kilowatts used for the time the current was on was calculated by taking the product of the average current and average voltage. This data was then corrected for grades. A grade of one per cent indicates an increase in height or altitude of one foot for every hundred feet of track. This is equivalent to exerting a negative force equal to one one-hundreth of the train weight,or twenty pounds per ton. If the grade is downward,the twenty pounds per ton was subtracted and for an up grade the twenty pounds was added. By dividing the kilowatts thus obtained by the weight of the car and passengers the kilowatts used per ton was obtained. This was then corrected for a constant voltage of five hundred. This data is found in tables III and IV.

As the brakes have to be applied on curves to steady the train and reduce the speed,the power used to supply the air is also a loss of power due to the curve. The power used to apply the brakes once,was obtained from a series of tests run on applying brakes. A number of application were made and the watt-hours used by the pump motor noted. By making several tests a good average for one application was obtained. This is found in table V. From data previously obtained it was found that the power consumed by the whistle in blowing for a curve is generally twice what it is for applying the brakes once.

TABLE III

Ball Bearing Center Plate — Power on 15 Sec.

Pole No	Degree of Curve	% Grade	Voltage	Current	K.W.	Weight of Car Corrected for Grade	K.W. per Ton	Extra K.W. per Ton for Curve
1443	0	0	500	93.5	46.75	49500	1.89	
1435	0	0	500	91	45.25	49500	1.83	
						Ave=	1.86	
1337	1°20'	0	500	94.5	47.25	49500	1.92	.06
1302	1°56'	-.1	500	95.5	47.75	49450	1.94	.08
1299	2°20'	0	500	95.8	47.9	49500	1.95	.07
1295	2°20'	0	500	96	48	49500	1.96	.10
511	3°30'	-.1	500	96.8	48.4	49450	1.99	.13
948	3°36'	-.53	500	97	48.5	49250	1.97	.11
384	4°36'	-.3	500	98	49	49200	2.0	.14
1217	4°40'	-.53	500	98.2	49.1	49250	2.0	.14
331	7°30'	.1	500	101.0	50.5	49550	2.06	.20
378	7°40'	0	500	104	52	49500	2.1	.24
1158	8°50'	.7	500	106.4	53.2	49250	2.16	.3
1165	9°20'	-.1	500	108.6	54.3	49450	2.2	.34

PLATE VII

Extra Power Used on Curves

Ball Bearing Center Plate

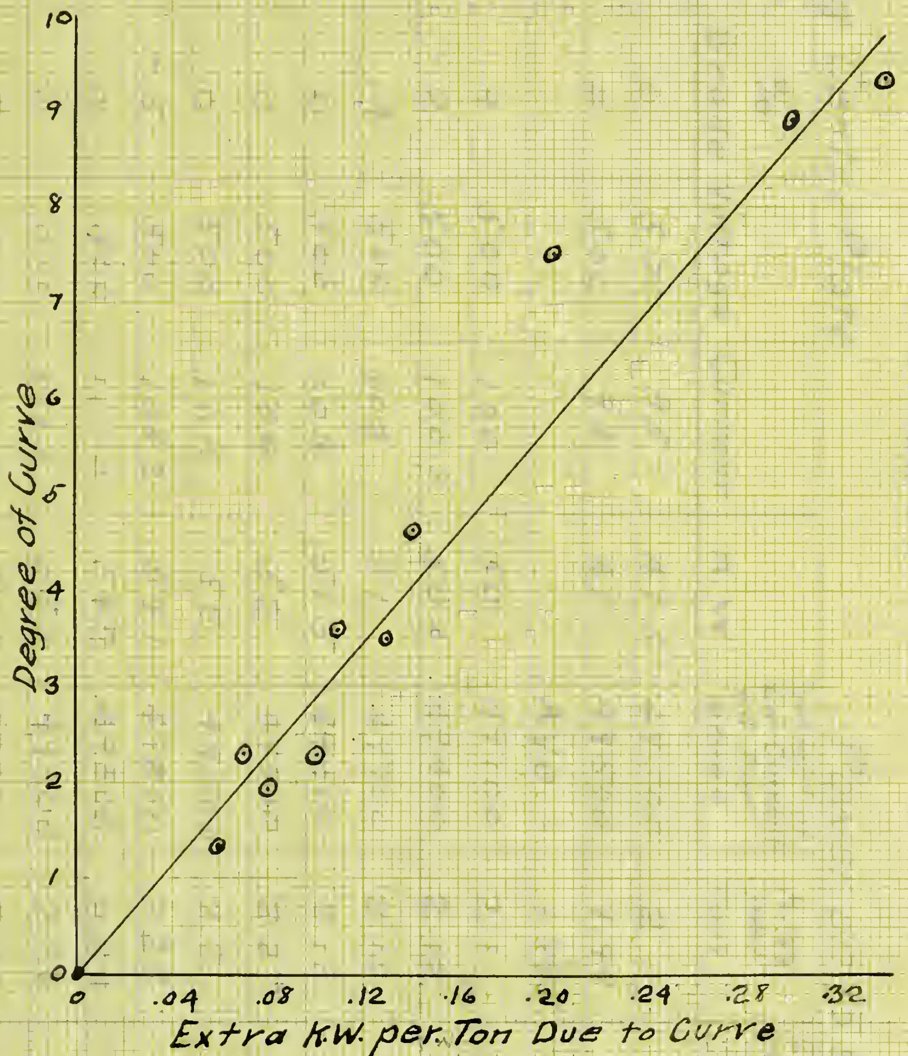

TABLE IV.

Slide Bearing Center Plate — Power on 15 Sec.

Pole No.	Degree of Curve	% Grade	Voltage	Current	K. W.	Weight of Car Corrected for Grade	K. W per Ton	Extra K.W. per Ton for Curve
1443	0	0	500	95	47.5	49500	2	
1435	0	0	500	94	47	49500	1.99	
						Ave =	1.995	
1225	1°	.4	500	100	50	49700	2.1	.115
444	1°12′	-.2	500	100.8	50.4	49400	2.12	.125
398	1°58′	.4	500	102	51	49700	2.15	.155
438	2°18′	0	500	103	51.5	49500	2.18	.185
948	2°18′	0	500	104	52	49500	2.2	.205
1299	2°20′	0	500	104	52	49500	2.2	.205
953	3°36′	-.5	500	108.2	54.1	49250	2.28	.275
595	3°4′	0	500	108.4	54.2	49500	2.29	.285
321	4°36′	2	500	111.6	55.8	49500	2.36	.365
381	4°36′	-.3	500	112.4	56.2	49350	2.38	.385
1190	6°30′	.26	500	116.6	58.3	49600	2.46	.465
322	7°30′	.1	500	124	62	49550	2.61	.615
378	7°40′	0	500	125	62.5	49500	2.64	.645

PLATE VIII

Extra Power Used on Curves

Slide Bearing Center Plate

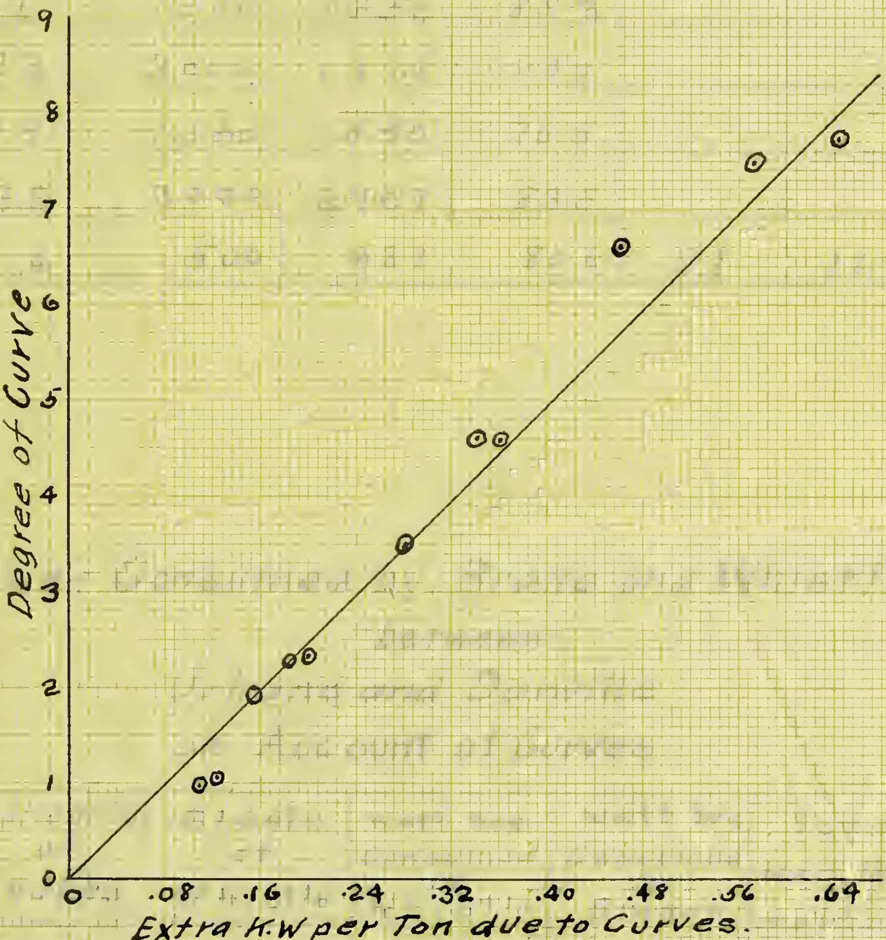

TABLE V.

Data on Brake and Whistle

No of Applications of Brakes	Meter Readings C = .969 W. Hr	True W. Hr	W. Hr. per Brake Application	Ave. W. Hr. per Brake Application	W. Hrs. per Blast of Whistle
11	1000	969	88		
42	3000	2907	69.4		
12	1000	969	80.6		
17	1500	1450	85.3		
23	2000	1938	84.2		
19	1500	1450	76.5		
35	3000	2907	83.5		
6	500	487	80.6	81	162

Power Consumed by Brake and Whistle between Urbana and Danville on Account of Curves.

Applications of Brakes	Blasts of Whistle	Watt hrs. Consumed by Whistle	Watt hrs. Consumed by Brakes	Total Watt Hrs.
60	32	5244	4860	10104

Turning again to plate V and VI,-- curves showing the time lost for different degrees of curvature,-- it is seen that the time lost does not increase in any direct ratio. Up to a certain degree of curvature the time lost was not noticable but as the degree of curvature increased the time lost increased. Beyond about a twenty degree curve the time lost increased very rapidly with the increase of curvature.

By comparison of plates V and VI,it is seen that the time lost due to curvature of track depends,to a great extent,upon the speed at which the curve is approached. The higher rate of speed, the longer it takes the car to slow down to a speed at which it can take the curve safely,and again the longer it will take the car to attain its original speed. Thus as far as time lost is concerned,it is quite evident that curves should be eliminated in the construction of a road,wherever it is deemed possible. A good instance of the time that may be saved is shown by table VI. The stations between Urbana and Danville are here listed,as are also the curves between each station. From plate V the time lost due to each curve is found and the total time lost due to each curve is found and the total time lost between each station is shown. The grand total of time lost between Urbana and Danville is quite appreciable especially in these days,when the civilized world is turning its attention to fast transportation. The svhedule time of limited cars between Urbana and Danville is one hour and ten minutes. With the curves straightened the cars now in operation could make the run

TABLE VI

Speed 30mi/hr.

Time Lost Between Urbana and Danville for Curves

Station	Degree of Curve	Time Lost Sec.	Station	Degree of Curve	Time Lost Sec.
Urbana			Mc Elwee		.5
	12°20'			1°20'	
	5°50'			1°	
	4°36'			4°40'	
	1°4'			2°46'	
	2°46'			4°50'	
	3°30'			24°	
Dodson		12.9		6°30'	
	4°58"		St. Joseph		24.9
	8°30'			9°20'	
	6°10'			8°50'	
Roe		8.9	Peabody		8.8
Cotton 'd		0	Glover		0
Mt. Olive		0	Hickory G.		0
Mayview		0	Wilson		0
Koch		0	Wagner		0
Peters		0	Hexenbaug		0
	56'			3°36'	
	1°20'			2°18'	
Kirkpatrick		.1	Ogden		1.7
	1°56'			28'	
	2°20'		Rumpler		0

TABLE VI continued.

Stations	Degree of Curve	Time Lost Sec.	Stations	Degree of Curve	Time Lost Sec.
	1°58'			10°40'	
	3°4'			11°30'	
	1°12'			11°40'	
Bronson		1.3		2°24'	
	3°4'		Hillory		35.4
	3°30'			12°30'	
	1°12'			32°20'	
	2°18'			2°18'	
Oakwood		2.7		8°	
	1°32'			8°50	
	1°58'			3°26'	
	2°52			58'	
	4°36			1°56'	
	7°40'			6°50'	
Mission Field		6.3		10°	
	1°42			13°50'	
	7°30'			11°20'	
	4°36'			3°	
	7°20'			45°	
	3°48'			12°	
	6°30'		Danville		115.5
	5°36'			Total	320

in about forty or fifty minutes and the schedule time would be cut down materially.

Another loss due to the curvature of the track is that of extra power required to run on curves. Tables III and IV contain data on the power consumption due to curves. This data is taken from a large number of runs and conditions were practically the same for all readings selected. By subtracting the kilowatts used on the different curves the loss due to the different degrees of curvature is obtained. The loss of kilowatts was used as abscissae and the degree of curvature as ordinates in plotting curves which show the relation of killowatts lost per ton to the degree of curvature of the track. Two such curves were plotted,one from the data obtained when the ordinary slide bearing center plate was on the car and the other,when the ballbearing center plate was in use. The loss of power increases directly with the degree of curvature, as is seen from plates VII and VIII.

The ball bearing center plates consume less power than the slide bearing,although it is a small item it is shown by a comparison of the data that the difference in power consumed is quite appreciable.

There have been several tests run to determine the loss due to curves and of all the separate tests run,very few have shown the same results. The New York and Erie Railroad take the value .7 pounds per ton for the train resistance due to one degree curve.

The Pennsylvania Road have adopted the value of .56 pounds per ton per degree of curve, while the Westinghouse Manufacturing Co. use the value of one pound per degree of curvature.

To an ordinary person, the applying of brakes and the warning signals of the whistle on curve, would not look like any expense of power to be considered at all. But from the data on table V, it is seen that each application of the brakes represent eighty-one watt hours. If the power used in pumping air for the brakes is compared with the power used to run the car, it will be seen that the brake power is quite an item in operating expense of the car.

As the whistle must be blown for each curve of any account, the power used to blow the whistle at these points is a loss due to the curves and must be figured as such. Ordinary estimates, is that it takes twice as much power for one blast of the whistle than is necessary for one application of the brakes.

There is still one more loss that is due to the curvature of track. That is the depreciation on wheels and distruction of the brake shoes. When it is considered that there are thirty five regular stops between Urbana and Danville and that the brakes must be applied sixty times due to the curves between the above mentioned points, it is evident that the life of the brake shoes is greatly diminished by the presence of the curves. If the curves were straightened the life of the brake shoes would be increased one hundred and seventy one per cent. The life of the brake shoes would be increased over two hundred per cent on the limited cars as they do

not make as many regular stops as the local cars.

In summing up the losses,mentioned above, it is seen that the ball bearing center plates are a means of saving power. The total losses due to curvature of track are time,power in operating car,power in application of brake shoes,besides wear on flanges,and rails which is increased very materially by the curves and is perhaps one of the most important features introduced by the existance of curves. Thus it is plain that the number of curves on a road should be reduced to a minimum for the economical operation of cars.